CS 194: Lecture 10

Bayou, Brewer, and Byzantine

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Agenda

- Review of Bayou
- Channeling Eric Brewer (CAP theorem)
- A peek at fault tolerance

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Review of Bayou

With examples!

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Why Bayou?

- Eventual consistency: strongest scalable consistency model
- But not strong enough for mobile clients
  - Accessing different replicas can lead to strange results
  - Application-independent conflict detection misses some conflicts and creates others falsely
- Bayou was designed to move beyond eventual consistency
  - Session guarantees
  - Application-specific conflict detection and resolution

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Bayou System Assumptions

- Variable degrees of connectivity:
  - Connected, disconnected, and weakly connected
- Variable end-node capabilities:
  - Workstations, laptops, PDAs, etc.
- Availability crucial

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Resulting Design Choices

- Variable connectivity ⇒ Flexible update propagation
  - Incremental progress, pairwise communication
- Variable end-nodes ⇒ Flexible notion of clients and servers
  - Some nodes keep state (servers), some don't (clients)
  - Laptops could have both, PDAs probably just clients
- Availability crucial ⇒ Must allow disconnected operation
  - Conflicts inevitable
  - Use application-specific conflict detection and resolution

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Components of Design

- Update propagation
- Conflict detection
- Conflict resolution
- Session guarantees

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Updates

- Identified by a triple:
  - Commit-stamp
  - Time-stamp
  - Server-ID of accepting server
- Updates are either committed or tentative
  - Commit-stamps increase monotonically
  - Tentative updates have commit-stamp=inf
- Primary server does all commits: (why?)
  - It sets the commit-stamp
  - Commit-stamp different from time-stamp

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Update Log

- Update log in order:
  - Committed updates (in commit-stamp order)
  - Tentative updates (in time-stamp order)
- Can truncate committed updates, and only keep db state
  - Why?
- Clients can request two views: (or other app-specific views)
  - Committed view
  - Tentative view

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Tentative vs Committed Views

- Committed view:
  - Updates will never be reordered
  - But may be substantially out-of-date
- Tentative view:
  - Much more current
  - But updates might be reordered
- Tradeoff is application-dependent:
  - Calendars: avoid tentative commitments, but don't count on them
  - Weather: being current more important than permanence

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Anti-Entropy Exchange

- Each server keeps a version vector:
  - R.V[X] is the latest timestamp from server X that server R has seen
- When two servers connect, exchanging the version vectors allows them to identify the missing updates
- These updates are exchanged in the order of the logs, so that if the connection is dropped the crucial monotonicity property still holds
  - If a server X has an update accepted by server Y, server X has all previous updates accepted by that server

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Requirements for Eventual Consistency

- Universal propagation: anti-entropy
- Globally agreed ordering: commit-stamps
- Determinism: writes do not involve information not contained in the log (no time-of-day, process-ID, etc.)

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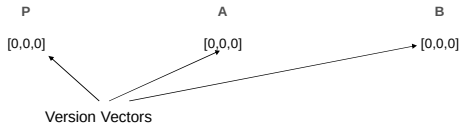
Example with Three Servers



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All Servers Write Independently

P	A	B
<inf,1,P> <inf,4,P> <inf,8,P>	<inf,2,A> <inf,3,A> <inf,10,A>	<inf,1,B> <inf,5,B> <inf,9,B>
[8,0,0]	[0,10,0]	[0,0,9]

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P and A Do Anti-Entropy Exchange

P	A	B
<inf,1,P> <inf,2,A> <inf,3,A> <inf,4,P> <inf,8,P> <inf,10,A>	<inf,1,P> <inf,2,A> <inf,3,A> <inf,4,P> <inf,8,P> <inf,10,A>	<inf,1,B> <inf,5,B> <inf,9,B>
[8,10,0]	[8,10,0]	[0,0,9]
↑	↑	
<inf,1,P> <inf,4,P> <inf,8,P>	<inf,2,A> <inf,3,A> <inf,10,A>	
[8,0,0]	[0,10,0]	

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P Commits Some Early Writes

P	A	B
<1,1,P> <2,2,A> <3,3,A> <inf,4,P> <inf,8,P> <inf,10,A>	<inf,1,P> <inf,2,A> <inf,3,A> <inf,4,P> <inf,8,P> <inf,10,A>	<inf,1,B> <inf,5,B> <inf,9,B>
[8,10,0]	[8,10,0]	[0,0,9]
↑		
<inf,1,P> <inf,2,A> <inf,3,A> <inf,4,P> <inf,8,P> <inf,10,A>		
[8,10,0]		

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P and B Do Anti-Entropy Exchange

P	A	B
<1,1,P> <2,2,A> <3,3,A> <inf,1,B> <inf,4,P> <inf,5,B> <inf,8,P> <inf,9,B> <inf,10,A>	<inf,1,P> <inf,2,A> <inf,3,A> <inf,4,P> <inf,8,P> <inf,10,A>	<1,1,P> <2,2,A> <3,3,A> <inf,1,B> <inf,4,P> <inf,5,B> <inf,8,P> <inf,9,B> <inf,10,A>
[8,10,9]	[8,10,0]	[8,10,9]
↑		↑
<1,1,P> <2,2,A> <3,3,A> <inf,4,P> <inf,8,P> <inf,10,A>		<inf,1,B> <inf,5,B> <inf,9,B>
[8,10,0]		[0,0,9]

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P Commits More Writes

P		P
<1,1,P> <2,2,A> <3,3,A> <inf,1,B> <inf,4,P> <inf,5,B> <inf,8,P> <inf,9,B> <inf,10,A>	→	<1,1,P> <2,2,A> <3,3,A> <4,1,B> <5,4,P> <6,5,B> <7,8,P> <inf,9,B> <inf,10,A>
[8,10,9]		[8,10,9]

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Bayou Writes

- Identifier (commit-stamp, time-stamp, server-ID)
- Nominal value
- Write dependencies
- Merge procedure

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Conflict Detection

- Write specifies the data the write depends on:
  - Set X=8 if Y=5 and Z=3
  - Set Cal(11:00-12:00)=dentist if Cal(11:00-12:00) is null

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Conflict Resolution

- Specified by merge procedure (mergeproc)
- When conflict is detected, mergeproc is called
  - Move appointments to open spot on calendar
  - Move meetings to open room

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Session Guarantees

- Ensured by client, not by distribution mechanism
- Needed to ensure user sees sensible results
- To implement, client records:
  - All writes during that session (write-set)
  - The writes relevant to each read read-set)
    - Must be supplied by server
    - Can be approximated by version vector

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The Four Session Guarantees

Guarantee	State updated	State checked
Read your writes	Write	Read
Monotonic reads	Read	Read
Writes follow reads	Read	Write
Monotonic writes	Write	Write

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Example

- Return to example with servers P, A, and B
- Client attaches to server P with vector [8,3,5]
- Client reads, with read-set {P6,A1,A2,B5}
- Client writes, with timestamp P9
- Client then detaches and reattaches to another server
- For which of these vectors can client read or write?

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What Reads/Writes are Allowed?

Read-set {P6,A1,A2,B5}, Write-set P9

- [7,1,6] Read Your Writes: No
  Monotonic Reads: No
  Writes Following Reads: No
  Monotonic Writes: No
  No R, No W
- [7,4,6] Read Your Writes: No
  Monotonic Reads: Yes
  Writes Following Reads: Yes
  Monotonic Writes: No
  No R, No W

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What Reads/Writes are Allowed?

Read-set {P6,A1,A2,B5}, Write-set P9

- [9,3,4] Read Your Writes: Yes
  Monotonic Reads: No
  Writes Following Reads: No
  Monotonic Writes: Yes
  No R, No W
- [10,3,8] Read Your Writes: Yes
  Monotonic Reads: Yes
  Writes Following Reads: Yes
  Monotonic Writes: Yes
  R, W

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Channeling Eric Brewer

Slightly more hair, much less wisdom

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A Clash of Cultures

- Classic distributed systems: focused on ACID semantics
  - A: Atomic
  - C: Consistent
  - I: Isolated
  - D: Durable
- Modern Internet systems: focused on BASE
  - Basically Available
  - Soft-state (or scalable)
  - Eventually consistent

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ACID vs BASE

ACID	BASE
▪ Strong consistency for transactions highest priority	▪ Availability and scaling highest priorities
▪ Availability less important	▪ Weak consistency
▪ Pessimistic	▪ Optimistic
▪ Rigorous analysis	▪ Best effort
▪ Complex mechanisms	▪ Simple and fast

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Why the Divide?

- What goals might you want from a shared-date system?
  - C, A, P
- **Strong Consistency**: all clients see the same view, even in the presence of updates
- **High Availability**: all clients can find some replica of the data, even in the presence of failures
- **Partition-tolerance**: the system properties hold even when the system is partitioned

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CAP Conjecture (later theorem)

- You can only have two out of these three properties
- The choice of which feature to discard determines the nature of your system

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Consistency and Availability

- Comment:
  - Providing transactional semantics requires all nodes to be in contact with each other
- Examples:
  - Single-site and clustered databases
  - Other cluster-based designs
- Typical Features:
  - Two-phase commit
  - Cache invalidation protocols
  - Classic DS style

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Consistency and Partition-Tolerance

- Comment:
  - If one is willing to tolerate system-wide blocking, then can provide consistency even when there are temporary partitions
- Examples:
  - Distributed databases
  - Distributed locking
  - Quorum (majority) protocols
- Typical Features:
  - Pessimistic locking
  - Minority partitions unavailable
  - Also common DS style
    - Voting vs primary replicas

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Partition-Tolerance and Availability

- Comment:
  - Once consistency is sacrificed, life is easy.…
- Examples:
  - DNS
  - Web caches
  - Coda
  - Bayou
- Typical Features:
  - TTLs and lease cache management
  - Optimistic updating with conflict resolution
  - This is the “Internet design style”

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Techniques

- Expiration-based caching: AP
- Quorum/majority algorithms: PC
- Two-phase commit: AC

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Byzantine

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Failures

- So far, have assume nodes are either up or down
- But nodes are far more interesting than that!

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Failure Models

Type of failure	Description
Crash failure	A server halts, but is working correctly until it halts
Omission failure *Receive omission* *Send omission*	A server fails to respond to incoming requests A server fails to receive incoming messages A server fails to send messages
Timing failure	A server's response lies outside the specified time interval
Response failure *Value failure* *State transition failure*	The server's response is incorrect The value of the response is wrong The server deviates from the correct flow of control
Arbitrary failure	A server may produce arbitrary responses at arbitrary times

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Previous Algorithms

- Only cope with crash-failure
- What happens if some other failure occurs?
- Bayou as an example:
  - If server lies about updates, algorithm gets hopelessly confused
- Generally, most other distributed protocols fail when faced with anything other than crash failures
- Next: how to deal with a wider variety of failures

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Same Dichotomy Exists

- Classic Distributed Systems:
  - Byzantine Algorithms
  - Two-phase Commit
- Internet style:
  - Checkable or “self-verifying” protocols
  - Very new field in Internet research
  - You now know as much as we do about it…..

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